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Geochemistry of ultrapotassic volcanic rocks in Xiaogulihe NE China: Implications for the role of ancient subducted sediments

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ABSTRACT

The unique eruptions of ultrapotassic volcanic rocks in eastern China reported so far took place in the Xiaogulihe area of western Heilongjiang Province, NE China. These ultrapotassic rocks are characterized by extremely high K_2O contents (>7 wt.%), abnormally unradiogenic Pb isotopic compositions ($^{206}Pb/^{204}Pb$ = 16.44–16.55; $^{207}Pb/^{204}Pb$ = 15.39–15.46; $^{208}Pb/^{204}Pb$ = 36.35–36.61), and moderately high $^{87}Sr/^{86}Sr$ ratios (0.7053–0.7057), which can be basically correlated with those of ultrapotassic igneous rocks distributed widely in northwestern America and Aldan Shield. The positive correlation between $^{187}Os/^{188}Os$ and 1/Os argues that these ultrapotassic rocks have probably experienced negligible lower continental crust addition (less than 1%) during magma ascent. The high contents of K_2O and negative correlation between $^{87}Sr/^{86}Sr$ and $^{206}Pb/^{204}Pb$ of these ultrapotassic rocks indicate the presence of a potassic phase, mostly phlogopite, in their mantle source. Their strong fractionation of rare earth elements and lack of Nd–Hf isotopic decoupling reveal a low-degree partial melting of garnet-bearing source rocks. In addition, the low CaO and Al_2O_3 contents of whole-rock compositions and low Fe/Mn ratios of olivine phenocryst chemistries suggest peridotites rather than pyroxenites as dominant source rocks for the Xiaogulihe ultrapotassic rocks. Based on these distinctive geochemical characteristics, we thus propose that the ultimate mantle source of the Xiaogulihe ultrapotassic volcanic rocks is phlogopite-bearing garnet peridotite within the lower part of the sub-continental lithospheric mantle (SCLM) that had been metasomatized by potassium-rich silicate melts. Combined with the unradiogenic Pb compositions, the most likely source of these potassium-rich silicate melts is the ancient subducted continental-derived sediments (>1.5 Ga). These ancient subducted sediments, possessing relatively low initial Pb isotopic compositions, had experienced large U/Pb fractionation during a subduction process, resulting in low-μ ($^{238}U/^{204}Pb$), and then accumulated in the mantle transition zone. The relatively low $^{87}Sr/^{86}Sr$ ratios of these ultrapotassic rocks also imply that their mantle source had evolved with low Rb/Sr ratios, which possibly resulted from the metasomatized melts derived from the ancient subducted sediments. This interpretation is quite different from previous hypotheses that attribute their unusual geochemical features to a dominantly asthenospheric source with a contribution from delaminated ancient SCLM, or a SCLM source that has been metasomatized by melts derived from deep asthenosphere or delaminated ancient lower continental crust.

1. Introduction

Interest in the petrogenesis of ultrapotassic igneous rocks increased greatly in the late 1970s with the discovery of diamond-bearing olivine lamproites in NW Australia (Atkinson et al., 1984). Because of their unusual geochemistry, distinctive mineralogy and potential to constrain the origin of an enriched mantle (EM) component, numerous works have been done to explain the magma genesis and mantle source evolution of these ultrapotassic rocks over the past 30 years (Avanzinelli et al., 2008; Chen et al., 2007; Chu et al., 2013; Davies et al., 2006; Foley and Peccerillo, 1992; Foley et al., 1987; Fraser et al., 1985; Kuritani et al., 2013; Mitchell and Bergman, 1991; Murphy et al., 2002; Nelson et al., 1986; Prelevic et al., 2008; Zhang et al., 1995; Zou et al., 2003).

Considering the distinctive geochemical characteristics of these ultrapotassic rocks, none of the previous studies have successfully and convincingly explained the nature and evolutionary history of their mantle sources, and many questions remain to be solved, such as the site of mantle sources, i.e. whether their ultimate sources are located within the SCLM (Avanzinelli et al., 2008; Chen et al., 2007; Chu et al., 2013; Davies et al., 2006; Prelevic et al., 2008; Zhang et al., 1995; Zou et al., 2003), asthenosphere (Choi et al., 2006) or the mantle transition zone (Kuritani et al., 2013; Murphy et al., 2002); and where the fluids

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and/or melts which metasomatized the ultimate mantle sources came from, i.e. deep asthenospheric mantle (McKenzie, 1989; Zhang et al., 2000), subduction zone (Elburg and Foden, 1999), delaminated SCLM (Choi et al., 2006; Zhao et al., 2014), mantle transition zone (Kuritani et al., 2013; Murphy et al., 2002) or delaminated lower continental crust (Chu et al., 2013); and also the source lithology of the potassium-rich rocks, i.e. whether they are peridotite or pyroxenite (Foley, 1992).

Cenozoic volcanic rocks, mostly alkaline basalts, are widely distributed in NE China and form an important part of the West Pacific volcanic zone (Basu et al., 1991; Chen et al., 2007; Choi et al., 2006; Chu et al., 2013; Kuritani et al., 2013; Liu et al., 1994; Zhang et al., 1995; Zhou and Armstrong, 1982; Zou et al., 2003). Among them, there are three potassic volcanic areas of Wudalianchi (WDLC), Erkeshan (EKS) and Keluo, called the WEK potassic volcanic field (Zhang et al., 1991). Detailed geochemical studies have revealed that the WEK potassic rocks displayed a clear EMI-like signature (Chen et al., 2007; Chu et al., 2013; Kuritani et al., 2013; Zhang, 1992; Zhang et al., 1991, 1995, 1998; Zou et al., 2003). Moreover, there is another volcanic field, around 200 km northwest to the WEK potassic volcanic field, called Xiaogulihe (Shao et al., 2009). The rocks here, having extremely high K_2O contents (over 7 wt.%) and K_2O/Na_2O ratios (over 2), can be classified as ultrapotassic rocks following the definition of Foley et al. (1987). Few investigations have been carried out on these ultrapotassic rocks so far, although they are distinct from all the Cenozoic basalts in eastern China in terms of their extremely high K_2O contents, mostly enriched incompatible elements, and very typical EMI-like isotopic signatures (especially the least radiogenic Pb isotopic compositions). In the following discussion, the term 'WEK potassium-rich volcanic rocks' will be used to substitute for the Xiaogulihe ultrapotassic volcanic rocks and the WEK potassic volcanic rocks.

In this study, we present, for the first time, major-, trace- and platinum group element (PGE) abundances and Sr–Nd–Hf–Pb–Os systematic isotopic compositions of the Xiaogulihe ultrapotassic volcanic rocks with aims to further understand the range of chemical and geodynamic processes that have contributed to the petrogenesis of these rocks. Consistent with previous studies, our results favor that the Xiaogulihe ultrapotassic rocks mainly originated from the lower SCLM that has been enriched through an ancient or recent metasomatic event. Moreover, we propose that the metasomatic melts were mainly derived from ancient continental-derived sediments subducted into the mantle transition zone with an oceanic plate. The metasomatized SCLM then experienced low-degree partial melting following a recent upwelling of asthenosphere and crustal attenuation in the Songliao Basin or continental rifting in the WEK potassium-rich volcanic rock belt.

2. Geological setting and sample descriptions

The WEK potassium-rich volcanic field, including the Xiaogulihe ultrapotassic volcanic field and the WEK potassic volcanic field, is located at the boundary between the northwestern margin of the Songliao Basin and the Great Xing'an Ranges, both of which are within the Xing'an–Mongolia Orogenic Belt (XMOB) (Fig. 1a). This NNW-trending, 400 km-long Cenozoic volcanic rock belt is one of the main potassium-rich volcanism areas in China.

The XMOB (Fig. 1a), generally considered as the eastern segment of the Central Asian Orogenic Belt, links the Siberian Craton in the north and the Sino-Korean Craton in the south (Li, 2006; Sengor and Natalin, 1996; Sengor et al., 1993; Tang et al., 2014; Xu et al., 2013; Zhou and Wilde, 2013). It is surrounded by the Paleo-Pacific orogens including the Mongolian–Okhotsk orogens in the north and Russian Far East orogens in the east, and separated from the Sino-Korean Craton by the Solonker–Xar Moron–Changchun–Yanji fault belt in the South (Li, 2006; Xu et al., 2013). The tectonic evolution of the XMOB was characterized by several significant events, including the evolution and final closure of the Paleo-Asian Ocean, the amalgamation of several micro-continental massifs (e.g. from west to east, the Erguna, Xing'an, Songliao, Jiamusi–Khanka massifs), and the subduction of the Paleo-Pacific Ocean (Li, 2006; Sengor and Natalin, 1996; Sengor et al., 1993; Tang et al., 2014; Xu et al., 2013).

The upwelling of asthenosphere and attenuation of continental crust in the Songliao Basin have been demonstrated by seismic, electric

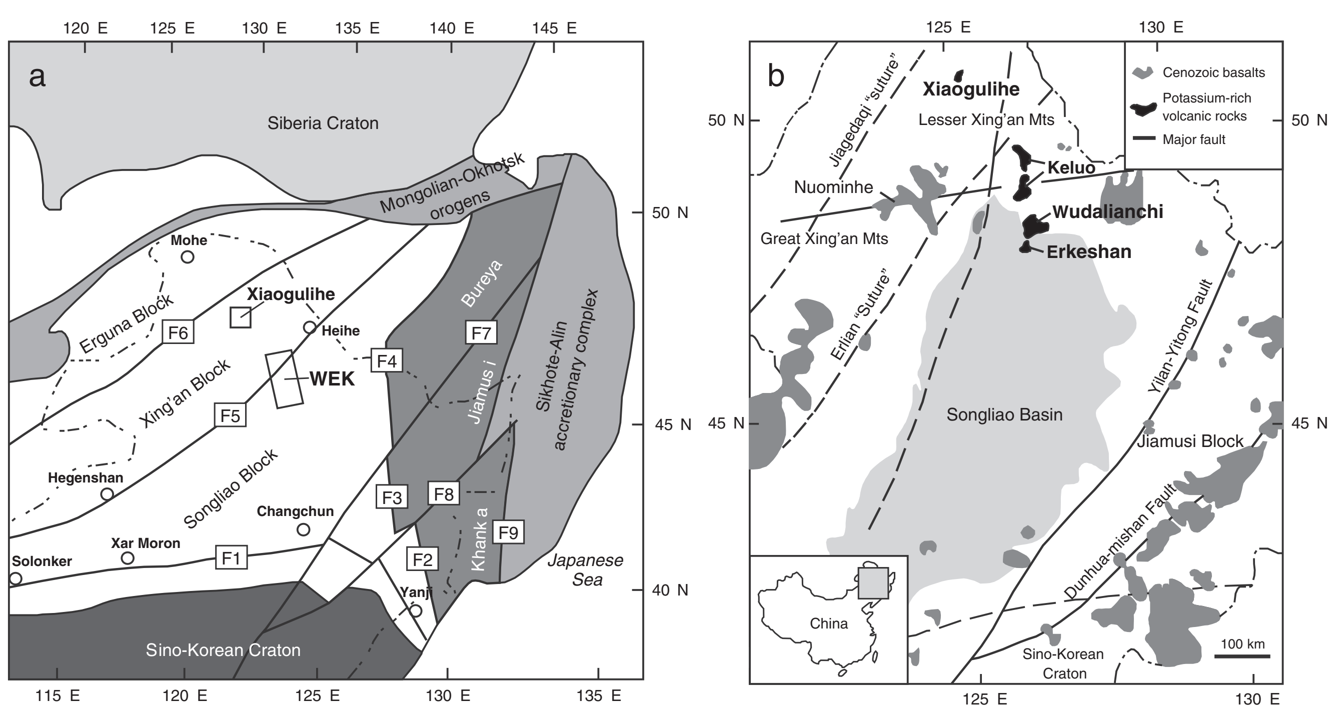

Fig. 1. (a) Tectonic framework of northeast China and Far East Russia (modified after Zhou and Wilde, 2013). F1 = Solonker–Xar Moron–Changchun zone; F2 = Yanji Fault; F3 = Mudanjiang Fault; F4 = Heilongjiang Fault; F5 = Hegenshan–Heihe Fault; F6 = Xinlin–Xiguitu Fault; F7 = Yilan–Yitong Fault; F8 = Dunhua–Mishan Fault, and F9 = Primoria Fault. (b) A sketch map showing major faults and the location of the Xiaogulihe, Keluo, Wudalianchi and Erkeshan potassium-rich volcanic rocks in NE China (modified after Zhang et al., 2000).